NACA

RESEARCH MEMORANDUM

AN EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF MACH NUMBER, STABILIZER DIHEDRAL, AND FIN TORSIONAL STIFFNESS ON THE TRANSONIC FLUTTER CHARACTERISTICS OF A TEE-TAIL

By Norman S. Land and Annie G. Fox

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON
October 23, 1957

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

AN EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF MACH NUMBER, STABILIZER DIHEDRAL, AND FIN TORSIONAL STIFFNESS ON THE TRANSONIC FLUTTER CHARACTERISTICS OF A TEE-TAIL

By Norman S. Land and Annie G. Fox

SUMMARY

A transonic flutter investigation was made of elastically and dynamically scaled models of the tee-tail of a patrol bomber. It was found that removal of the 15° dihedral of the stabilizer used on the airplane raised the flutter boundary to higher dynamic pressures. The effect of Mach number on the flutter boundary was different for dihedral angles of 0° and 15°. The dynamic pressure at the flutter boundary increased approximately linearly with the torsional stiffness of the fin. High-speed motion pictures indicated that the flutter mode consisted primarily of fin bending and fin torsion.

INTRODUCTION

Several airplanes have been designed and built with tee-tails, that is, with the horizontal stabilizer at, or near, the top of the vertical fin. Such configurations are interesting from the standpoint of the effects of the horizontal stabilizer on the bending-torsion flutter characteristics of the fin. Several effects of a rigid stabilizer on fin flutter speeds may be anticipated. A drop in the natural frequencies of the fin occurs because of the added mass and inertia of the stabilizer. Also, the inertia coupling between fin bending and fin torsional modes of vibration is changed by the addition of the stabilizer, particularly if the stabilizer is swept. An experimental investigation of these effects is reported in reference 1. In addition to these mass effects, the stabilizer may be expected to have some aerodynamic effects. Changes in the center of pressure and lift-curve slope of the fin may be caused by the presence of the stabilizer. Another aerodynamic effect is that the geometric dihedral of the stabilizer and the additional dihedral effect due

to the sweep of the stabilizer will alter the coupling between fin bending and torsion. That is, any fin torsion causes a stabilizer yaw which produces a rolling moment that results in fin bending.

In the present investigation, the flutter characteristics of dynamically and elastically scaled models of the tee-tail of a patrol bomber airplane were determined in the Mach number range from 0.7 to 1.4. The effects of variations in dihedral angle of the stabilizer and in torsional stiffness of the fin were studied.

SYMBOLS

η	nondimensional coordinate along quarter-chord line, expressed as fraction of exposed quarter-chord line
x_α	distance from elastic axis to airfoil center of gravity, measured normal to quarter-chord line in semichords, positive if center of gravity is rearward of elastic axis
I_α	mass moment of inertia per unit length about elastic axis, slug-ft^2/ft
b	semichord normal to quarter-chord line, ft
b_r	semichord normal to quarter-chord line at intersection of quarter-chord line and panel root, ft
m	mass of panel per unit length along quarter-chord line, slugs/ft
r_α	nondimensional radius of gyration of panel section about elastic axis, $\left(I_\alpha/mb^2\right)^{1/2}$
a	distance from midchord to elastic axis, measured normal to quarter-chord line in semichords, positive if elastic axis is rearward of midchord
I_x	mass moment of inertia of stabilizer in roll, slug-ft^2
I_y	mass moment of inertia of stabilizer in pitch, slug-ft^2
I_z	mass moment of inertia of stabilizer in yaw, slug-ft^2

ρ	airstream density, slugs/cu ft
q	airstream dynamic pressure, lb/sq in.
M	Mach number
V	airstream velocity, ft/sec
f	frequency of vibration, cps
f_{hh}	measured first coupled lateral bending frequency of fuselage (model installed), cps
f_{hfc}	measured first coupled bending frequency of fin, clamped as a cantilever, cps
f_{hsc}	measured first coupled bending frequency of stabilizer panels, with fin clamped as cantilever, cps
GJ	fin torsional stiffness, lb-in.^{2}

MODELS

General Description of Models

The flutter models used in this investigation had the dimensions given in figure 1 and were designed to simulate the tail of the full-scale airplane dynamically and elastically. Also, the models were so mounted as to simulate two fuselage modes of vibration: side bending and torsion. The frequencies of the models were 24 times those of the airplane, while the linear dimensions of the models were 1/24 of the airplane dimensions. The masses of the model were 1/6912 of the masses of the airplane. With this scale factor, the model at sea-level air density represented the airplane at an altitude of 21,500 feet.

All the models were of the same construction with the stiffness of the panels concentrated in hollow box spars of aluminum alloy. (See fig. 2.) Chordwise rigidity was attained through the use of aluminum-alloy ribs with channel cross sections. The aerodynamic shape of the fin and stabilizer was achieved by the addition of balsa filler between the ribs and mahogany leading and trailing edges. The entire panel structure was then covered with lacquered silk. Photographs of some of the models are shown in figures 3 to 6.

The models were divided into three groups. The first group consisted of nine models, all having elastic properties scaled from those

of the prototype airplane. Seven of these models (models 1, 2, 3, 4A, 6, 7, and 8) were essentially similar and each had a stabilizer with 15° of dihedral, as did the airplane. Each of the other two models of this group (models 4 and 5) had a stabilizer with no dihedral. This first group of models was used to investigate the effects of Mach number and dihedral.

A second group of models (models 1A and 2A) had 15° of stabilizer dihedral but had a fin torsional stiffness approximately twice that of the first group. A third group of models (models 5A, 6A, and 7A) had a fin torsional stiffness intermediate to that of the first two groups and also had stabilizers with 15° of dihedral.

The airplane fuselage degrees of freedom were simulated by rigidly attaching the model to the free end of a spring which was cantilevered from the wind-tunnel fuselage mount. (See fig. 7.) Bending of this spring simulated lateral fuselage bending, and torsion of the spring simulated fuselage torsion.

Structural Properties of Models

In general, the methods used in measuring the structural properties of the models were the same as those previously reported in reference 2. All physical properties of all models were not determined because a determination of panel mass and inertia distribution requires sawing the panel into sections, and most of the models were destroyed by flutter. The mass and inertia properties of the fin and stabilizer of a representative model of the first group are given in table I.

The natural frequencies and the associated node lines that were obtained on the models are presented in figure 8. Some frequencies were obtained with the root of the fin clamped and the fin and stabilizer cantilevered from this clamp, representing the rigid-fuselage condition. Other measurements were made with the fuselage degrees of freedom present. In all cases, the model was excited by a moving coil vibrator driven by an audio-oscillator. For the cantilever clamping, the vibrator was positioned near the root of the panel. In determining the frequencies with the fuselage degrees of freedom present, the vibrator was rigidly attached to the fuselage near the root of the model. Node lines were observed by sprinkling table salt on the panels.

A typical stabilizer with bullet fairing attached was swung as a compound pendulum and the moments of inertia about the principal axes were determined and are presented in table I.

APPARATUS AND TESTS

The tests reported in this paper were conducted in the Langley transonic blowdown tunnel, which has a 26-inch test section. The tunnel and its operation for flutter tests are described in detail in reference 3. As in previous tests, the fuselage on which the model was mounted extended forward into the subsonic flow region of the entrance cone in order to eliminate bow-shock-wave reflection interference. However, for these tests, the fuselage was mounted below the center line of the tunnel so that the horizontal stabilizer would be approximately centered in the tunnel. A sketch of the setup is given in figure 9.

Oscillograph records of stagnation pressure, stagnation temperature, and test-section static pressure provided a knowledge of the air-stream conditions. Information on the deflections of the fin in bending and torsion was obtained through the use of strain gages mounted on the root of the fin. Records of all these quantities were made simultaneously by a multichannel oscillograph as a time history of each run. This instrumentation is similar to that used in previous flutter tests and described in reference 3.

The first series of tests was made to investigate the effects of dihedral and Mach number on the flutter characteristics.

The second series of tests was made to determine the effect of torsional stiffness of the fin on the flutter boundary at one Mach number (approximately 0.9).

A third series of tests was conducted to study the effects of a few miscellaneous parameters at one Mach number. One model (5A) was tested with the fuselage degrees of freedom locked out. The effect of increasing the moment of inertia of the stabilizer was investigated by adding 5 grams of lead to the leading edge at the tip of each panel of the stabilizer (model 5A-1). This added weight was approximately 3.0 percent of the weight of the unmodified stabilizer. Two models were used to get limited data on the effect of shifting the stabilizer center of gravity. One of these models (7A) was modified by adding 30 grams of lead to the center of the bullet fairing and was then designated model 7A-1. The other model (6A) was tested first with 30 grams of lead in the tail of the bullet fairing and subsequently, as model 6A-1, with the weight moved to the nose of the bullet fairing. This added weight was approximately 17.5 percent of the weight of the unmodified stabilizer. Model 6A was not tested without the added weights; however, it was similar to model 7A, which was tested without added weights. Bending and torsion frequencies (model cantilevered) were determined to be 65.5 and 122 cycles per second, respectively, for model 6A before any weight was added.

Each model when mounted in the tunnel was adjusted to zero yaw and zero angle of attack before any flutter points were determined. This was done by observing the static deflection of the model at an airstream dynamic pressure somewhat below the flutter boundary, and then making the necessary adjustments to the fuselage mounting.

RESULTS AND DISCUSSION

A study of high-speed motion pictures that were made of some of the models during flutter indicated that the flutter mode was made up primarily of fin bending and fin torsional motions. The models with stabilizer dihedral experienced more violent flutter than the models with no stabilizer dihedral. Examination of the oscillograph records showed that the onset of sustained flutter was clearly defined for all the models and that the region of low damping, as evidenced by intermittent flutter, was small. All the flutter data that were obtained are listed in table II.

The effects of stabilizer dihedral and Mach number on flutter are indicated in figure 10. The free-stream dynamic pressure at the start of flutter is presented as a function of Mach number for the models with and without stabilizer dihedral but otherwise closely alike. It can be seen that throughout the range of test Mach numbers the presence of stabilizer geometric dihedral adversely affected the flutter boundary. This result is attributed to an aerodynamic coupling between fin bending and fin torsion caused by the geometric dihedral. No attempt was made to investigate the dihedral effect due to sweep (which varies with the lift coefficient). It can also be seen in figure 10 that the effect of Mach number is widely different for the models with and without stabilizer dihedral. The flutter boundary for the models with stabilizer dihedral rises to higher values of dynamic pressure as the Mach number increases, with an apparent tendency toward leveling off to a limiting value of dynamic pressure. The flutter boundary for the models with no stabilizer dihedral is characterized by a minimum dynamic pressure for flutter at a Mach number near 1.0, with the flutter boundary rising to higher values of dynamic pressure at lower and higher Mach numbers. The reasons for the different effects of Mach number are not understood. It is conjectured, however, that the very important aerodynamic coupling caused by the geometric dihedral may not be greatly affected by Mach number; therefore, the flutter boundary for the models with stabilizer dihedral varies rather slowly with Mach number. For the case of zero dihedral, however, the aerodynamic characteristics of the fin itself may be of much greater importance and the interference between stabilizer and fin may be such as to cause large changes in center of pressure and lift-curve slope on the fin over a relatively narrow range of Mach numbers.

The effect of fin torsional stiffness on the dynamic pressure at which flutter occurs is shown in figure 11 for a Mach number of approximately 0.9. The indication is that the dynamic pressure for flutter increases almost linearly with fin torsional stiffness through the range of stiffness investigated.

The magnitude of the effect on the flutter boundary of shifting the position of the 30-gram lead weight in the bullet fairing and the magnitude of the effect of locking out the fuselage degrees of freedom are both within the scatter of the basic data. The data of figure 11 indicate that the increase in stabilizer moment of inertia had no appreciable effect on the flutter boundary.

SUMMARY OF RESULTS

Transonic flutter tests of dynamically scaled models of the tee-tail of a patrol bomber airplane yielded the following results:

1. The flutter mode appeared to be composed primarily of fin bending and fin torsion.

2. Removal of the 15° of stabilizer dihedral incorporated in the airplane raised the flutter boundary to higher dynamic pressures throughout the transonic Mach number range.

3. For the models with dihedral, the dynamic pressure at the start of flutter increased with an increase in Mach number.

4. For the models with no dihedral, the flutter boundary was at a minimum dynamic pressure near a Mach number of 1 and rose to considerably higher pressures at lower and higher Mach numbers.

5. The dynamic pressure at the start of flutter increased with fin torsional stiffness.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 4, 1957.

REFERENCES

1. Pengelly, C. D., Wilson, L. E., Epperson, T. B., and Ransleben, G. E., Jr.: Flutter Characteristics of a T-Tail. WADC Tech. Rep. 52-162 (Contract No. AF 33(038)-18404), Wright Air Dev. Center, U. S. Air Force, Nov. 1954.

2. Land, Norman S., and Abbott, Frank T., Jr.: Transonic Flutter Investigation of a Fighter-Airplane Wing Model and Comparison With a Systematic Plan-Form Series. NACA RM L55B16, 1955.

3. Unangst, John R., and Jones, George W., Jr.: Some Effects of Sweep and Aspect Ratio on the Transonic Flutter Characteristics of a Series of Thin Cantilever Wings Having a Taper Ratio of 0.6. NACA RM L55I13a, 1956.

TABLE I.- PHYSICAL PROPERTIES OF A REPRESENTATIVE MODEL

$$\left[I_X = 0.00102 \text{ slug-ft}^2;\ I_Y = 0.00034 \text{ slug-ft}^2;\ I_Z = 0.00148 \text{ slug-ft}^2\right]$$

η	x_α	r_α^2	a	m, slugs/ft	b/b_r
Fin					
0.523	0.159	0.241	-0.352	0.01176	0.777
.571	.156	.240	-.349	.01102	.757
.620	.148	.232	-.346	.01100	.731
.669	.150	.227	-.346	.01046	.709
.718	.148	.219	-.336	.01038	.683
.767	.187	.264	-.342	.01894	.660
.815	.124	.214	-.332	.00928	.639
Stabilizer					
0.338	0.108	0.221	-0.297	0.00723	0.882
.392	.097	.217	-.282	.00705	.851
.446	.040	.255	-.297	.00580	.822
.501	.203	.290	-.292	.00951	.793
.555	.108	.205	-.297	.00565	.765
.609	.151	.211	-.300	.00522	.738
.663	.099	.219	-.304	.00707	.713
.718	.234	.251	-.303	.00544	.688
.772	.144	.269	-.306	.00391	.661
.826	.216	.357	-.320	.00344	.632
.881	.171	.228	-.301	.00687	.603
.935	.207	.384	-.321	.00358	.579
.989	.178	.325	-.323	.00302	.556

TABLE II.- EXPERIMENTAL FLUTTER DATA

Model	ρ, slugs/cu ft	q, lb/sq in.	M	V, ft/sec	f, cps	Stabilizer dihedral, deg
2	0.0054	13.83	0.843	860	90	15
3	.0035	14.62	1.140	1,093	82	
7	.0049	14.61	.948	924	87	
6	.0050	10.98	.788	798	100	
6	.0063	11.63	.727	729	100	
6	.0048	11.59	.816	836	100	
6	.0054	13.36	.812	841	85	
8	.0044	12.27	.901	896	80	
1	.0030	14.89	1.246	1,202	84	
4	.0089	20.97	.840	825	85	0
5	.0044	16.66	1.097	1,047	85	
5	.0044	17.88	1.123	1,083	85	
5	.0047	14.54	.941	944	77	
5	.0042	20.90	1.268	1,193	88	
5	.0049	17.62	1.044	1,020	86	
5	.0078	19.08	.876	839	85	
2A	.0069	18.44	.898	875	100	15
1A	.0065	17.90	.909	889	112	
4A	.0040	10.74	.862	872	80	
1A	.0070	19.92	.916	907	100	
5A	.0064	13.32	.922	939	100	
6A	------	13.08	.869	-----	80	
7A	.0083	16.74	.952	937	85	
5A-1	.0075	14.95	.922	922	84	
6A-1	.0084	16.31	.924	912	86	
7A-1	.0082	16.42	.941	929	83	

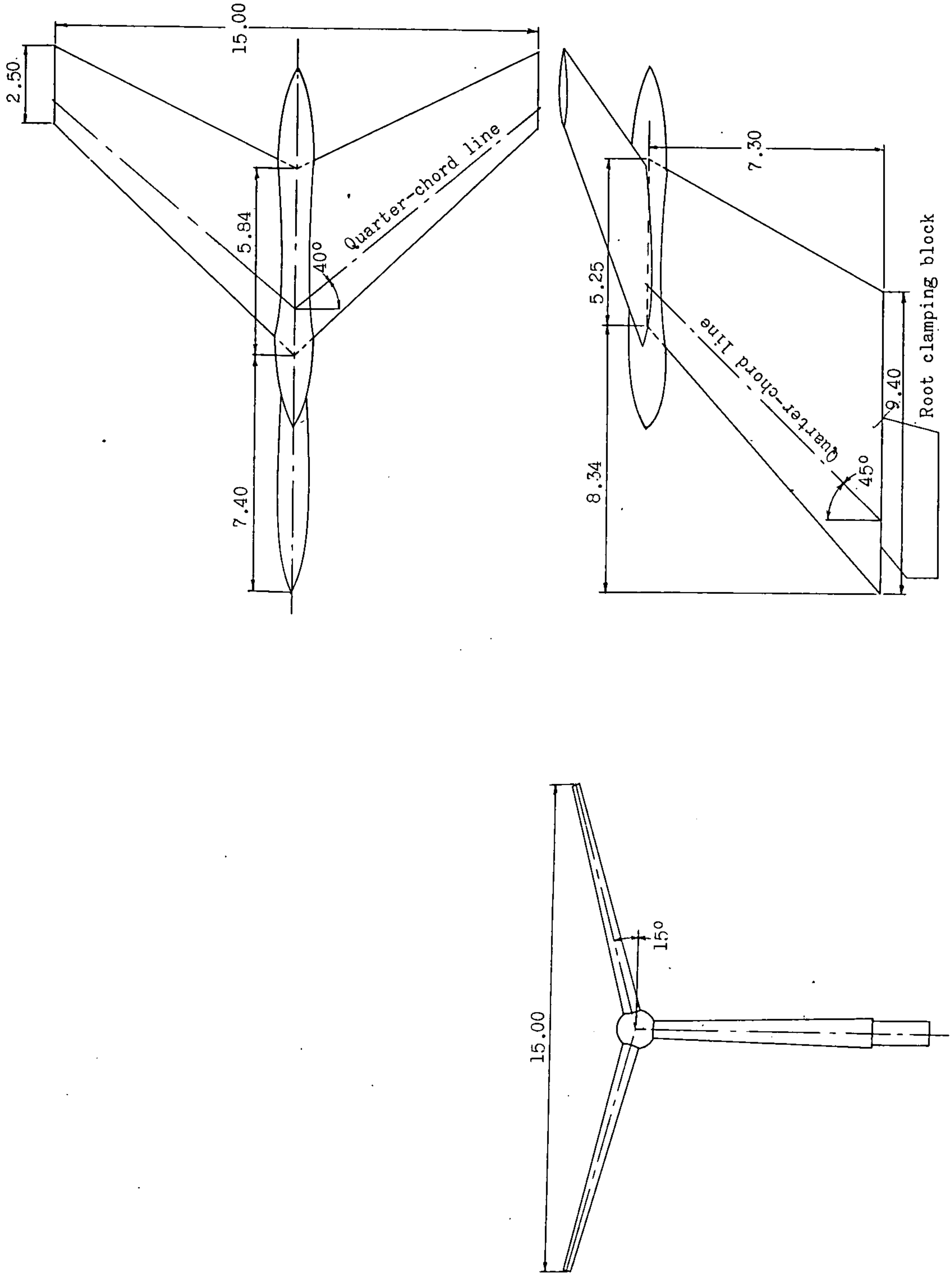


Figure 1.- Details and dimensions of model with dihedral. All dimensions are in inches.

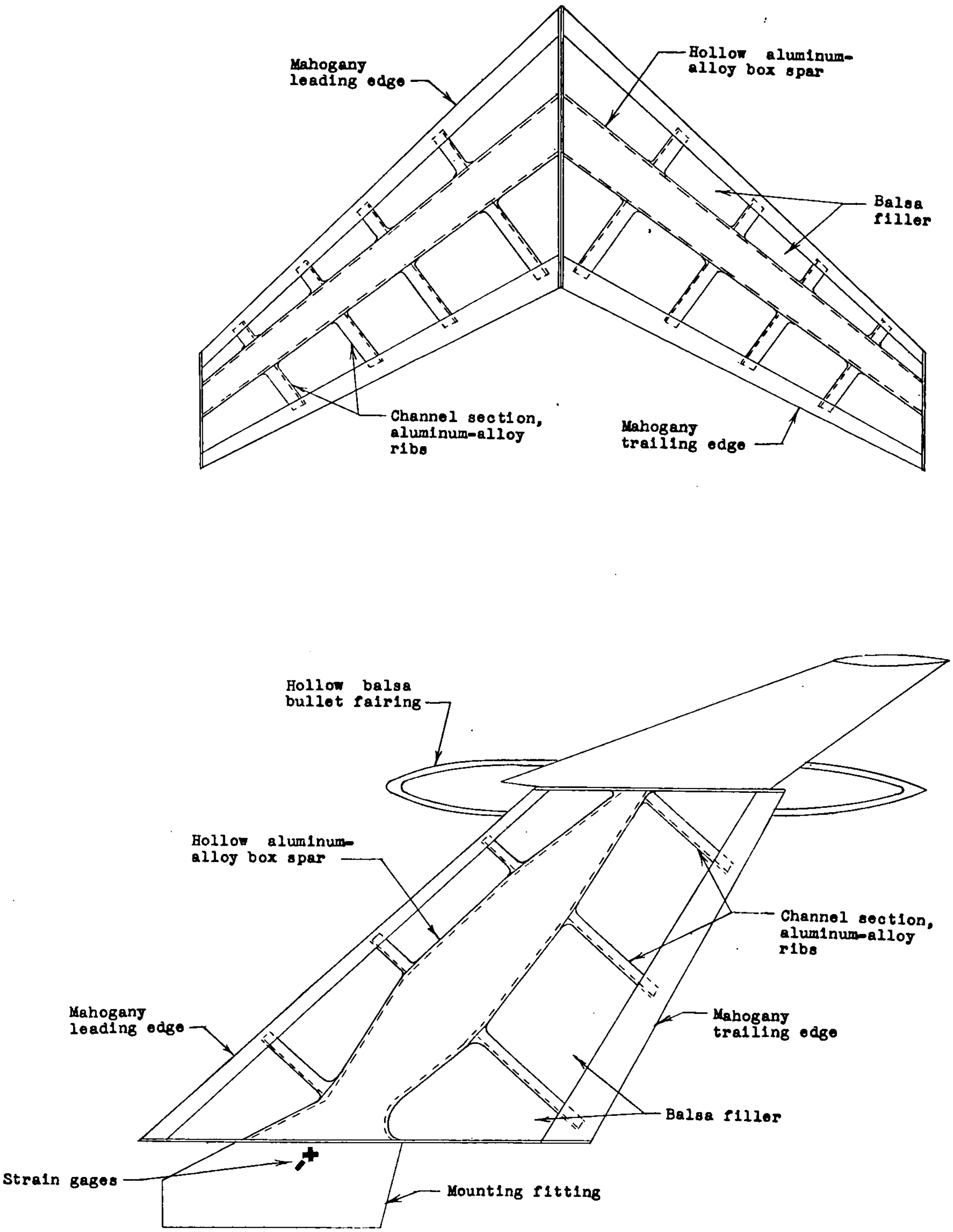


Figure 2.- Model construction.

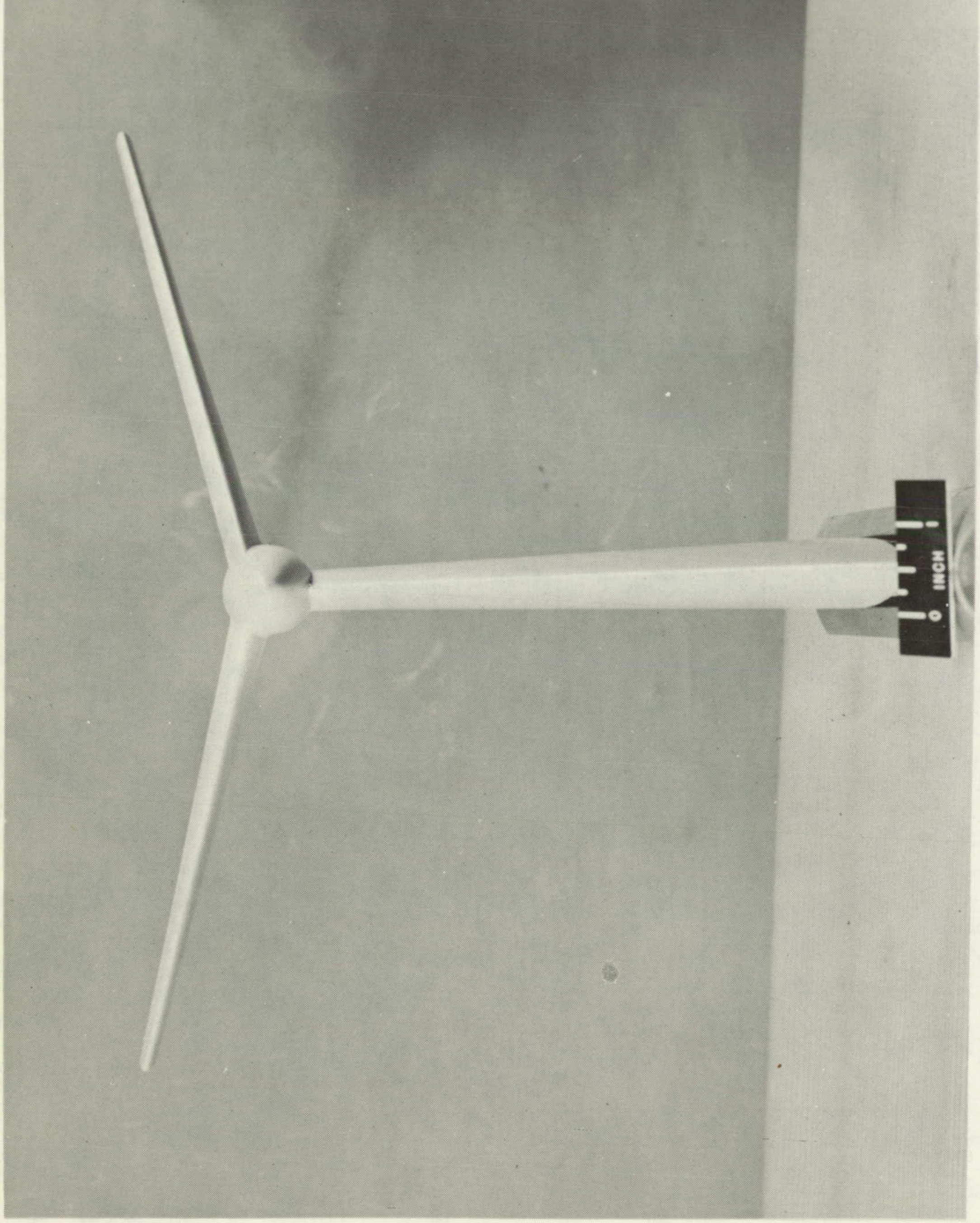


Figure 3.- Front view of model with dihedral. L-93128

Figure 4.- Front view of model with no dihedral. L-92578

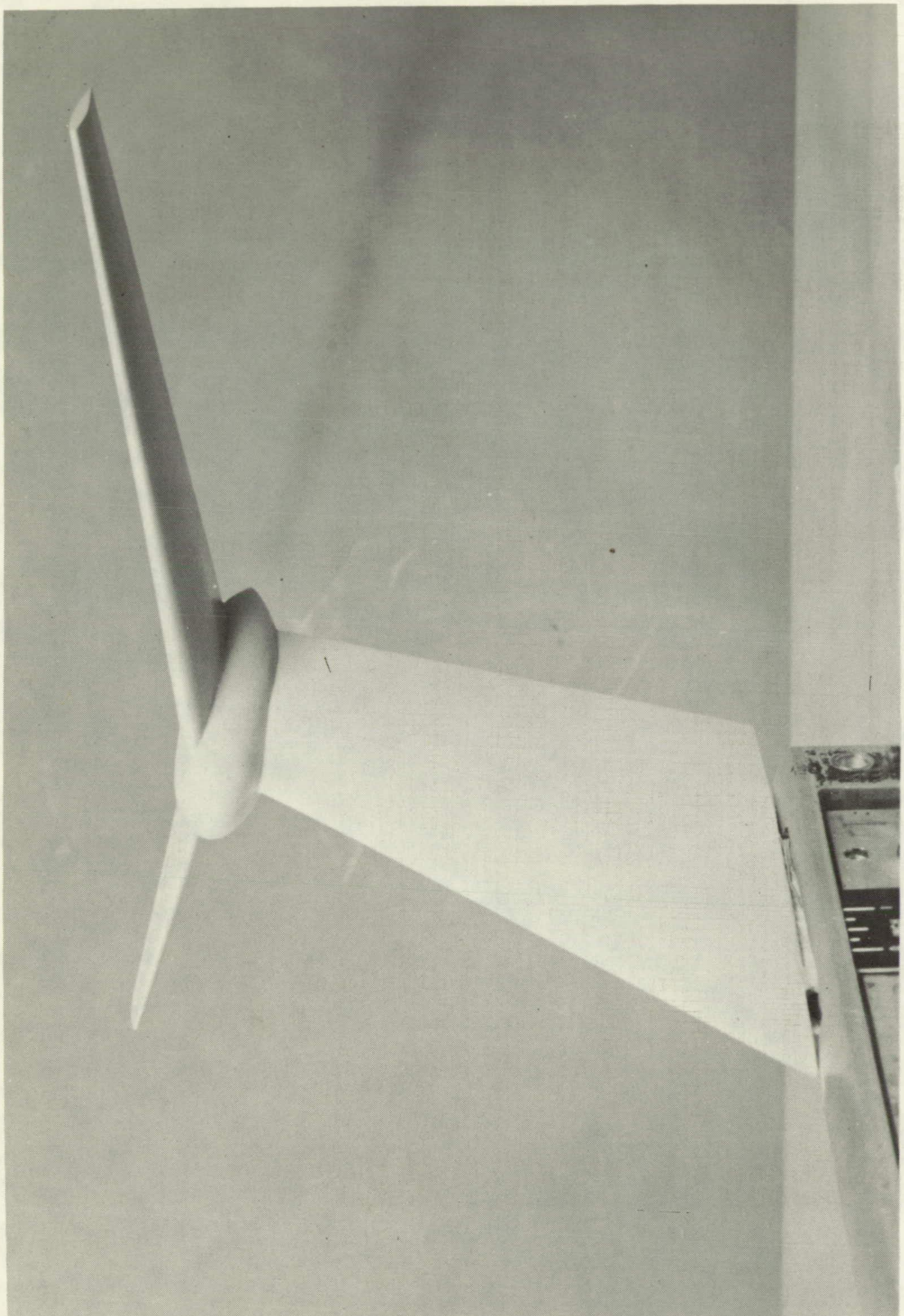


Figure 5.- Three-quarter front view of model with dihedral. L-93126

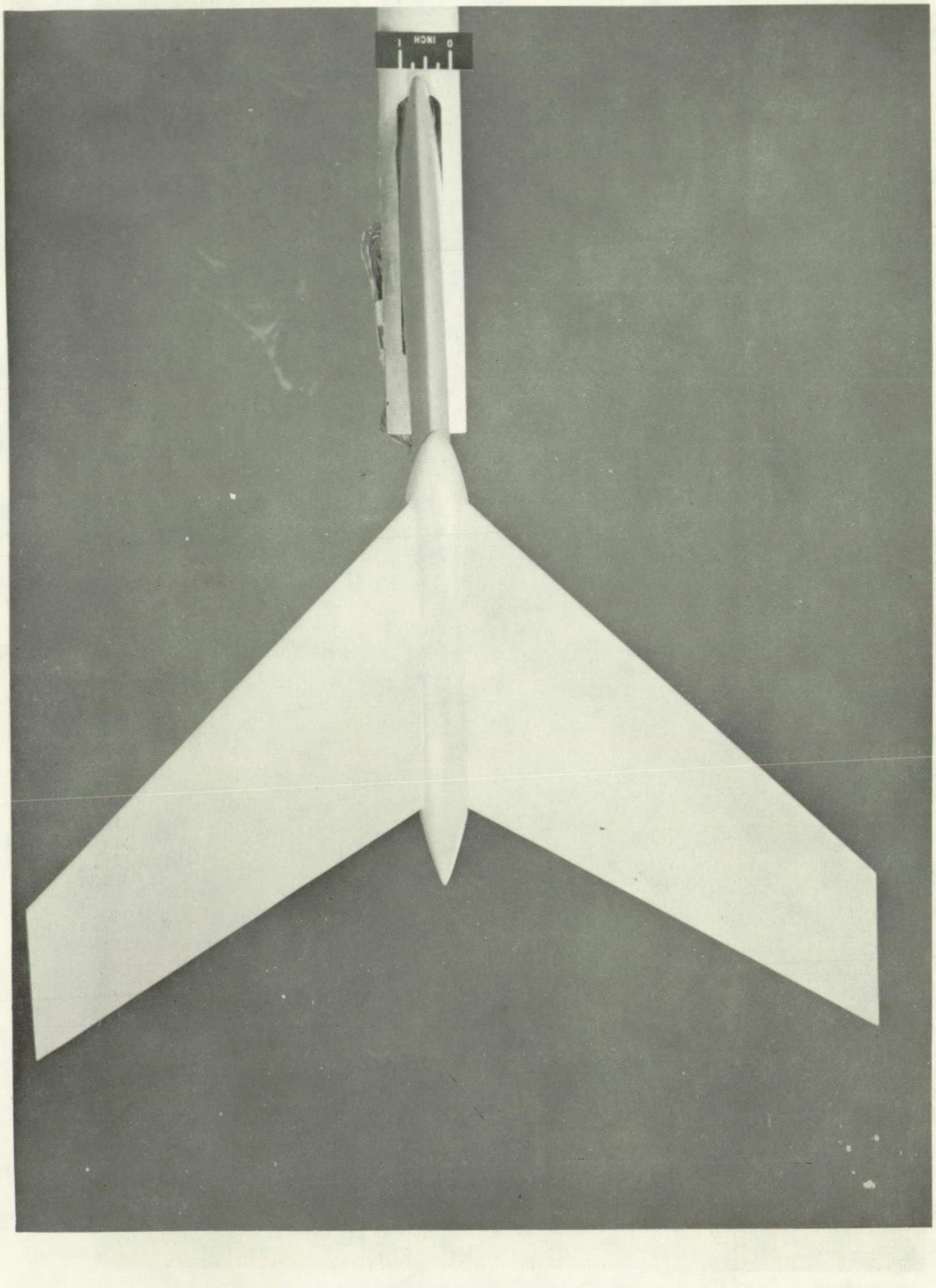


Figure 6.- Top view of model. L-93127

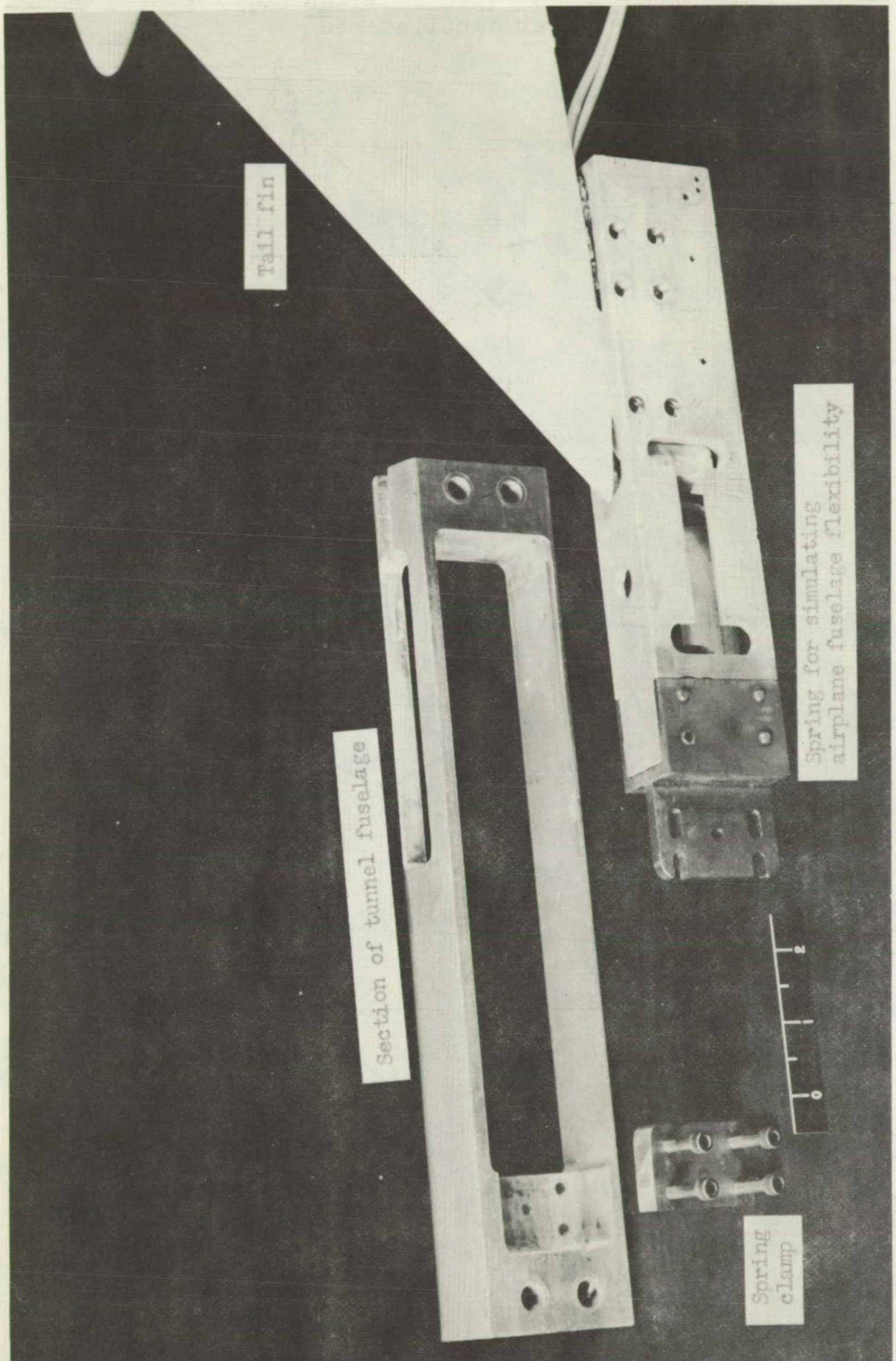


Figure 7.- Model mounting fixture. L-94132.1

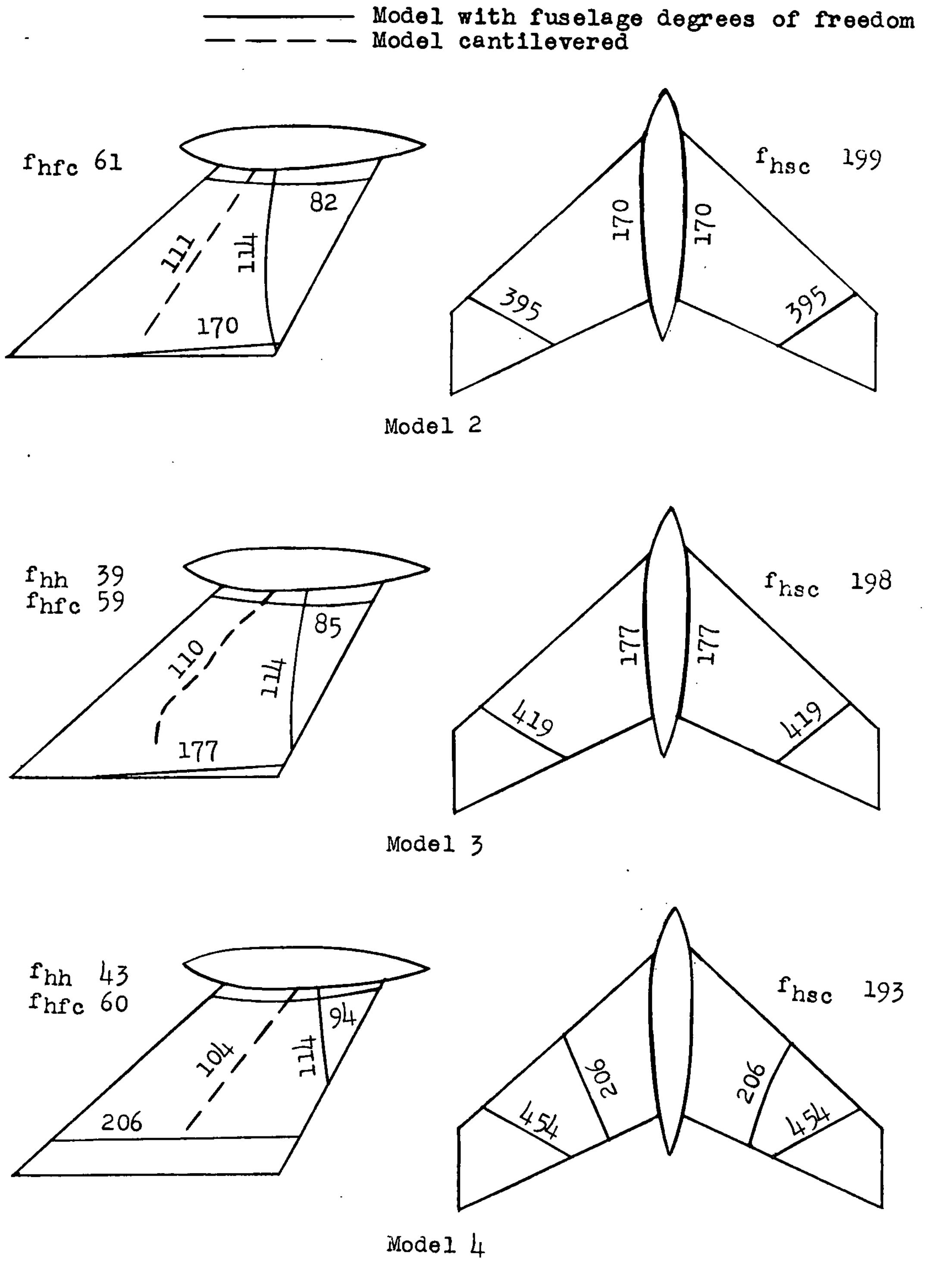
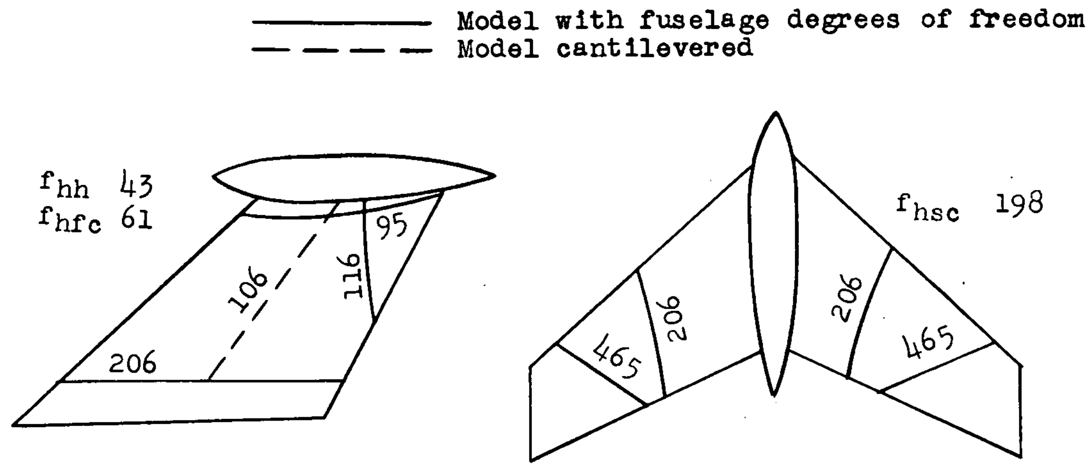
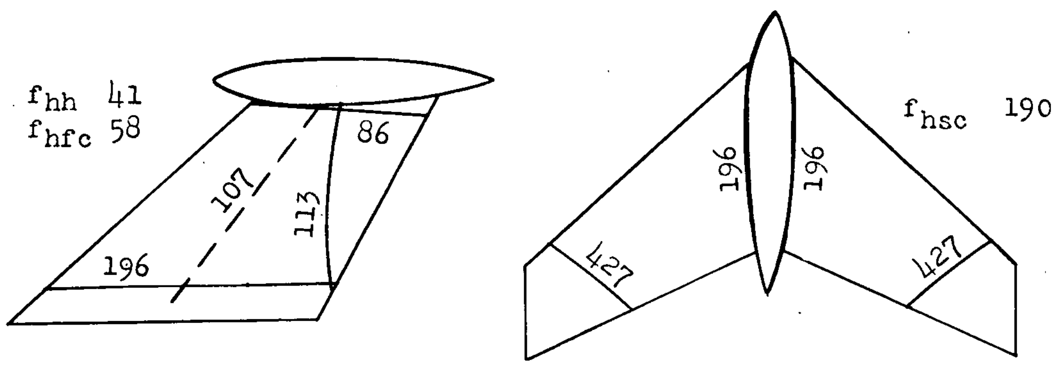


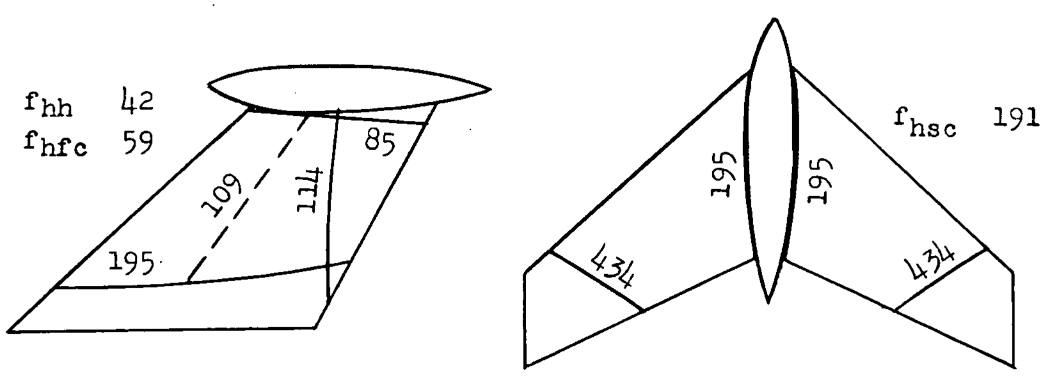
Figure 8.- Node lines and frequencies.



Model 5



Model 6



Model 7

Figure 8.- Continued.

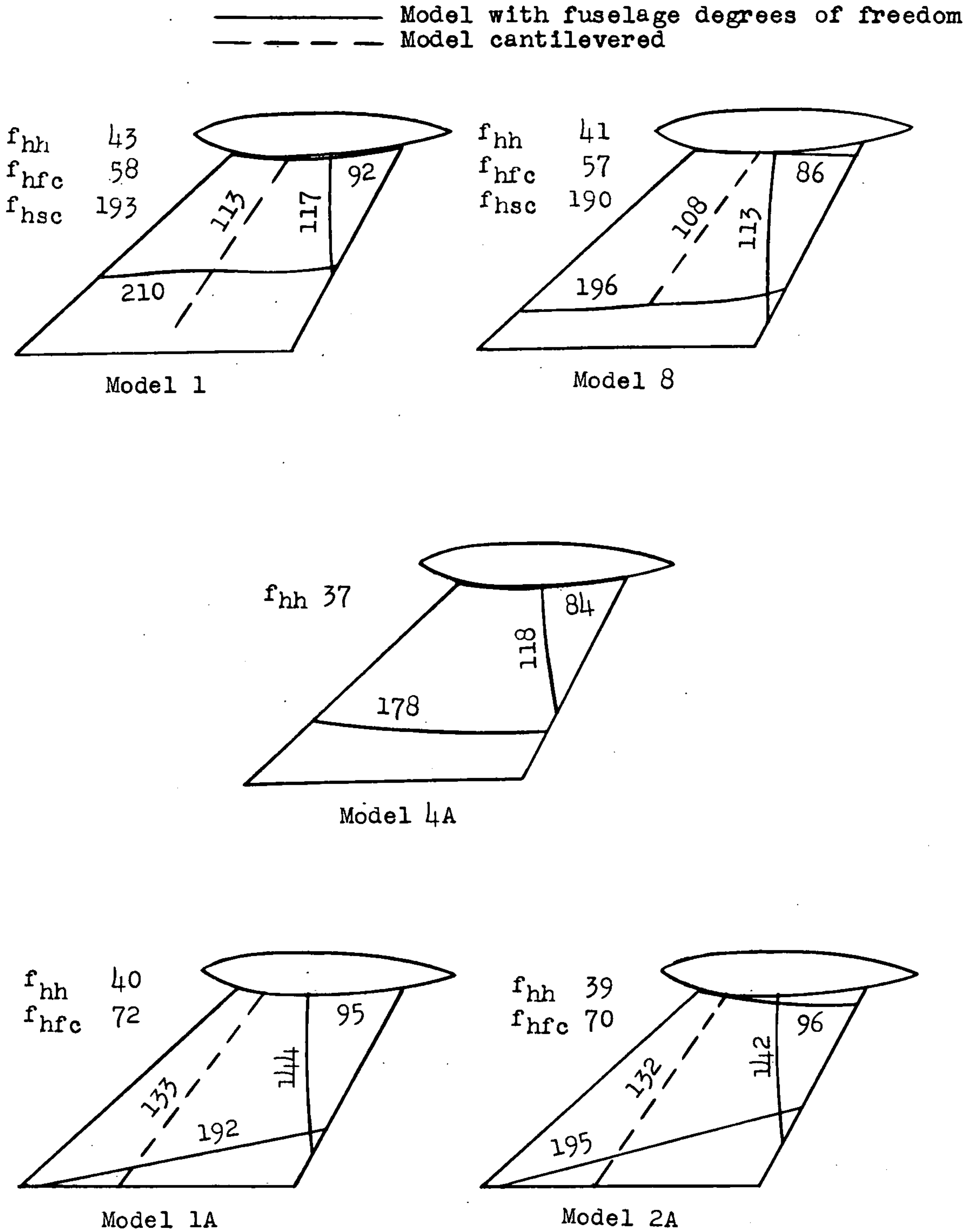


Figure 8.- Continued.

Model 5A-1: 5 grams of lead in each panel tip of stabilizer
Model 6A: 30 grams of lead in tail of bullet fairing
Model 6A-1: 30 grams of lead in nose of bullet fairing
Model 7A-1: 30 grams of lead in center of bullet fairing

Model with fuselage degrees of freedom
Model cantilevered

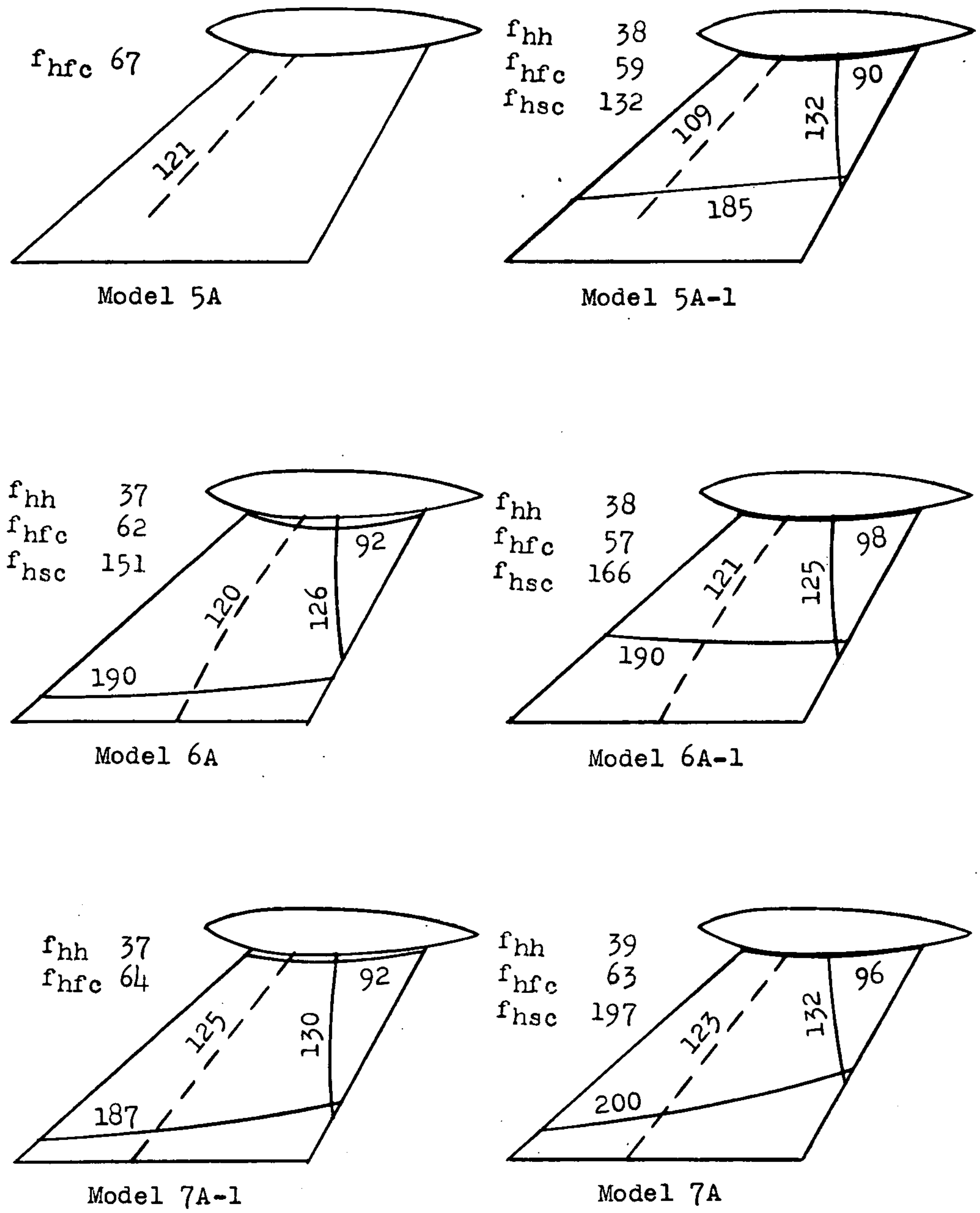


Figure 8.- Concluded.

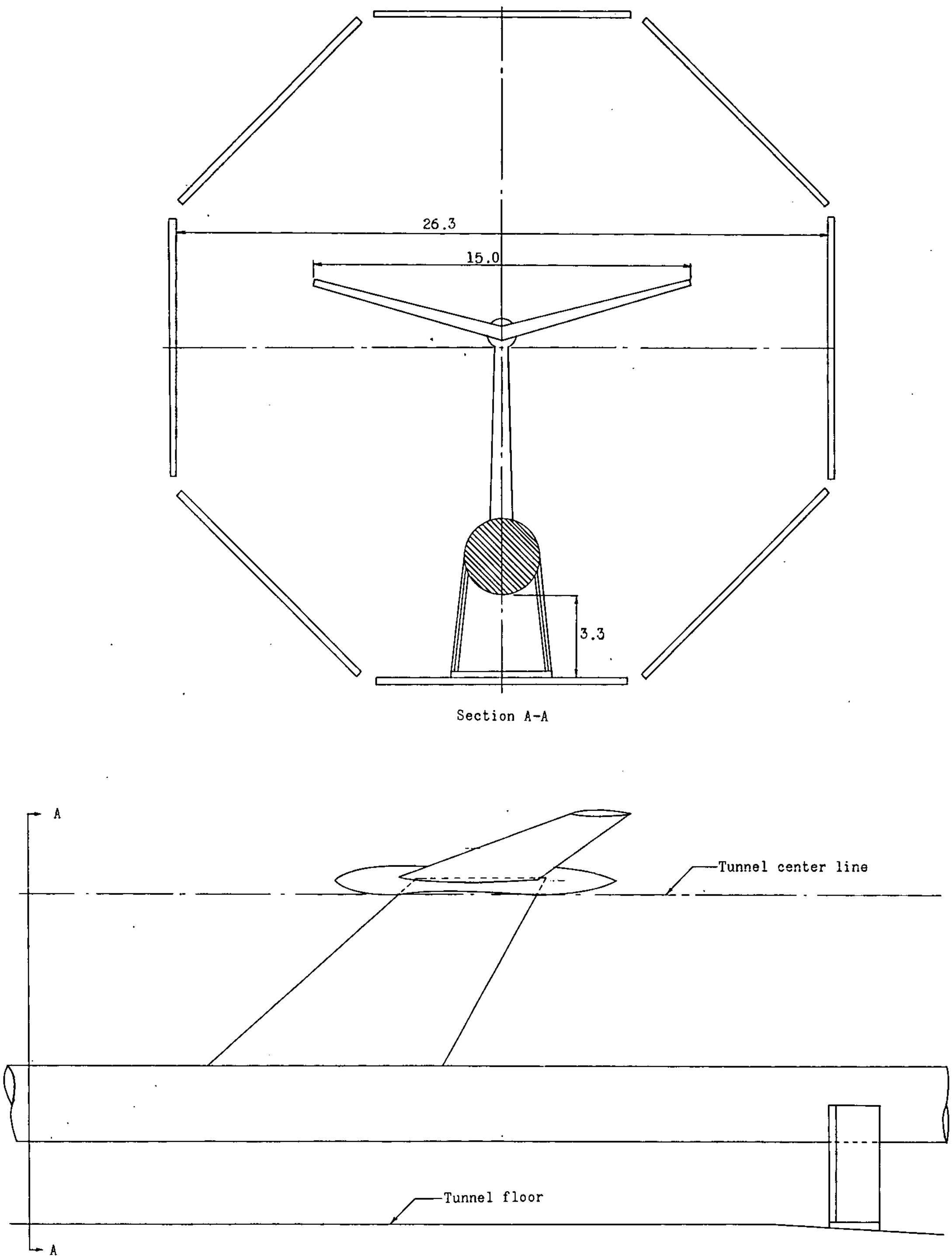


Figure 9.- Sketch of model mounted in tunnel. All dimensions are in inches.

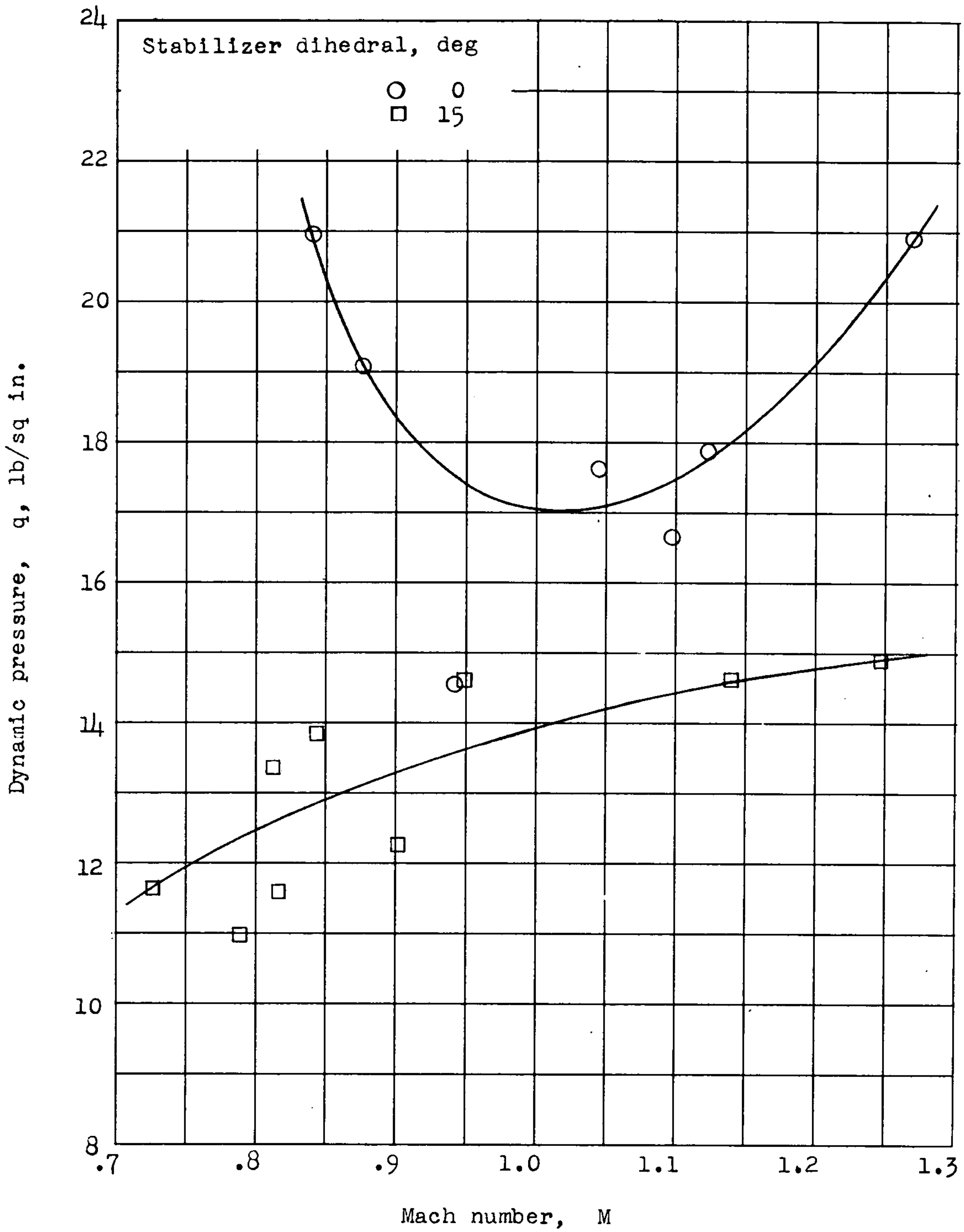


Figure 10.- Effect of Mach number on dynamic pressure at flutter for two tails with different amounts of stabilizer dihedral.

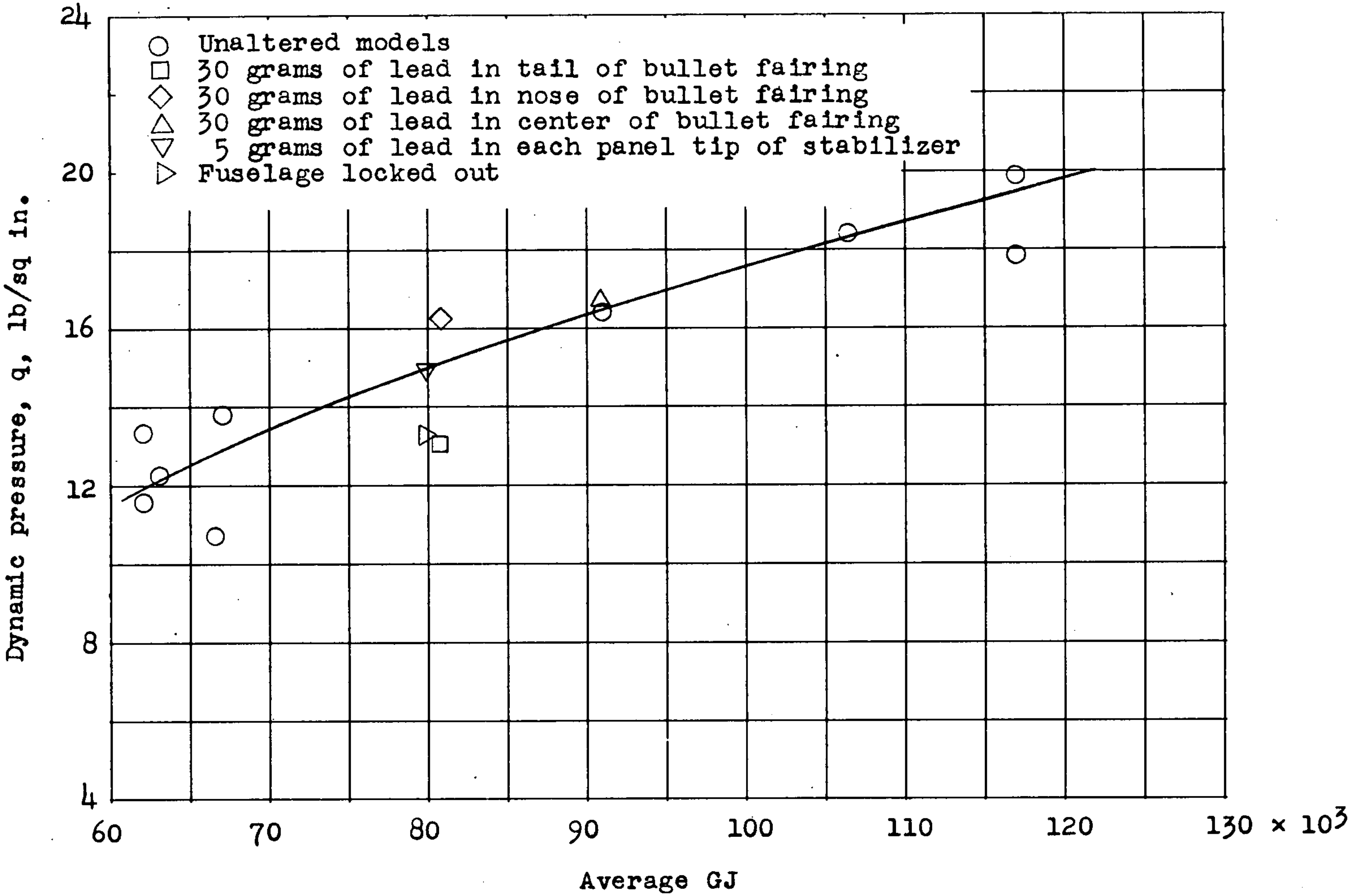


Figure 11.- Effect of torsional stiffness of fin on dynamic pressure at flutter. Mach number approximately 0.9.

NACA - Langley Field, Va.

CONFIDENTIAL

CONFIDENTIAL